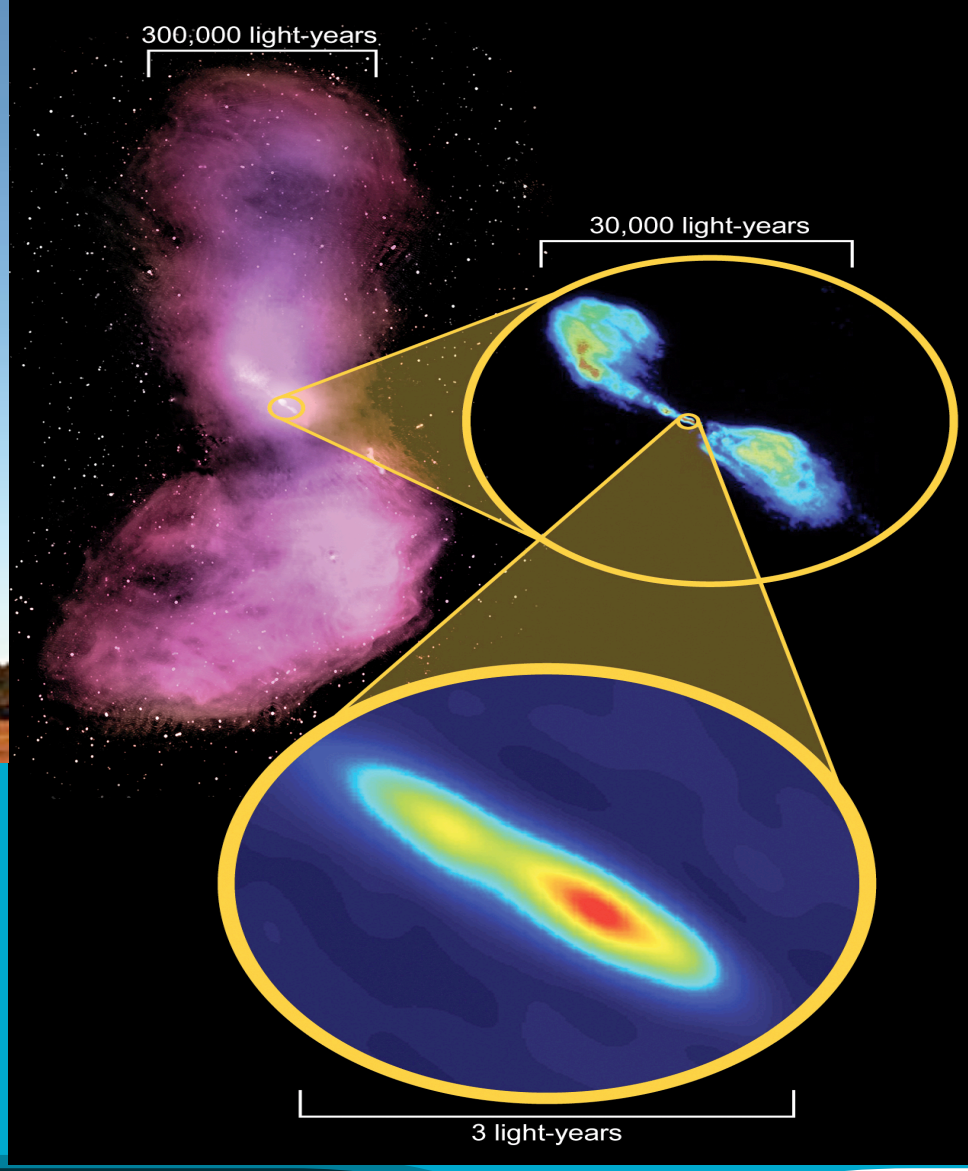

Radio Astronomy & Radio Telescopes

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Australia Telescope National Facility (ATNF)

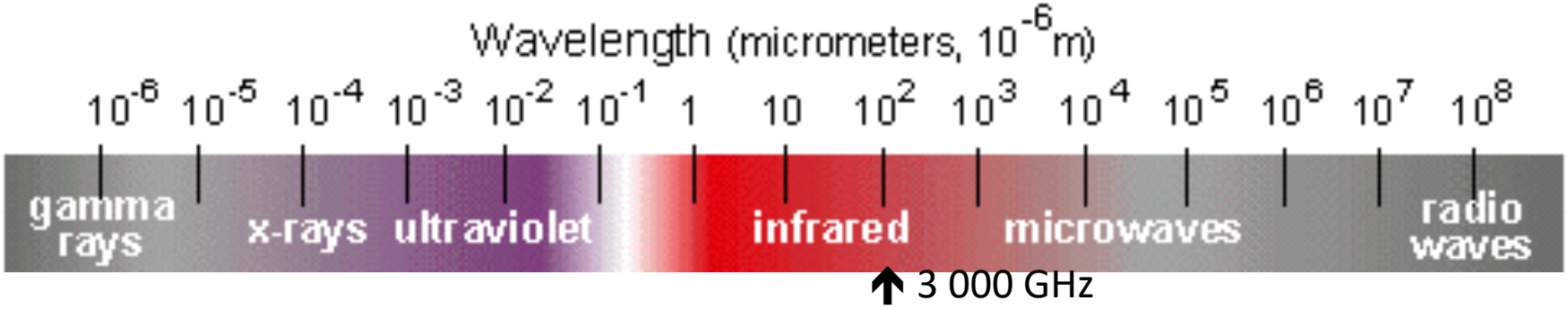
sms2020, Stellenbosch 2-6 March 2020

Radio Astronomy – ITU definition

1.13 *radio astronomy:* Astronomy based on the reception of *radio waves* of cosmic origin.

1.5 *radio waves* or *hertzian waves:* Electromagnetic waves of frequencies arbitrarily lower than 3 000 GHz, propagated in space without artificial guide.

- Astronomy covers the whole electromagnetic spectrum
- Radio astronomy is the "low energy" part of the spectrum



Radio Astronomy "special" characteristics Technical challenges

- Very **faint** signals – measured in 10^{-26} W/m^2/Hz (-260 dBW)
  - *"Power collected by all radiotelescopes since the start of radio astronomy would light a 1W bulb for less than 1 second"*
  - → Need "**sensitivity**" i.e. **large** antennas and/or **arrays** of many antennas
  - → Very **susceptible** to intereference
- Celestial structures at all scales: from very large to very small
  - → Need "**spatial resolution**" i.e. ability to see the details at all scales
  - → Need **large** antennas and/or **arrays** of many antennas
- Astronomical events at all timescales(from < 1ms to > millions years) & and at all spectral resolutions (from < 1 Hz to GHz)
  - → Need very high **time** and **frequency resolution**

- **→ Sensitive telescopes and arrays & extreme technical challenges**

Radio Astronomy “special” characteristics Scientific challenges

- Radio can “see” through dust and clouds
  - Probe space inaccessible to “traditional astronomy”
- Radio is a large part of the EM spectrum
  - Access unique phenomena and physics
- Radio spectrum contains many spectral “lines”
  - Markers of molecules and atoms – **astrochemistry**
  - Frequencies fixed and cannot be chosen
  - → Need access to special portions of the spectrum
- Universe is expanding (since the Big Bang)
  - Doppler shift (**redshift**) moves the lines to other parts of the spectrum!!
- Sensitivity (continuum) depends on Bandwidth – need spectrum!
- **→ Need access to ALL parts of the radio spectrum!!**

Special window to the Universe

- Radio astronomy only ~ 60 years old
- Many phenomena occur only in radio
- **→ 4 Nobel prizes in Physics!!!**
  - 1974 – Aperture synthesis and Pulsars
  - 1978 – Cosmic Microwave Background (discovery)
  - 1993 – Pulsars and Gravitational effects
  - 2006 – Cosmic Microwave Background (form and anisotropy)

- Technical challenges produce significant commercial spin-offs
  - State-of-the-art antennas and receivers for communications
  - E.g. wi-fi development at CSIRO from radio astronomy techniques
    - Commercial patent of many $100M

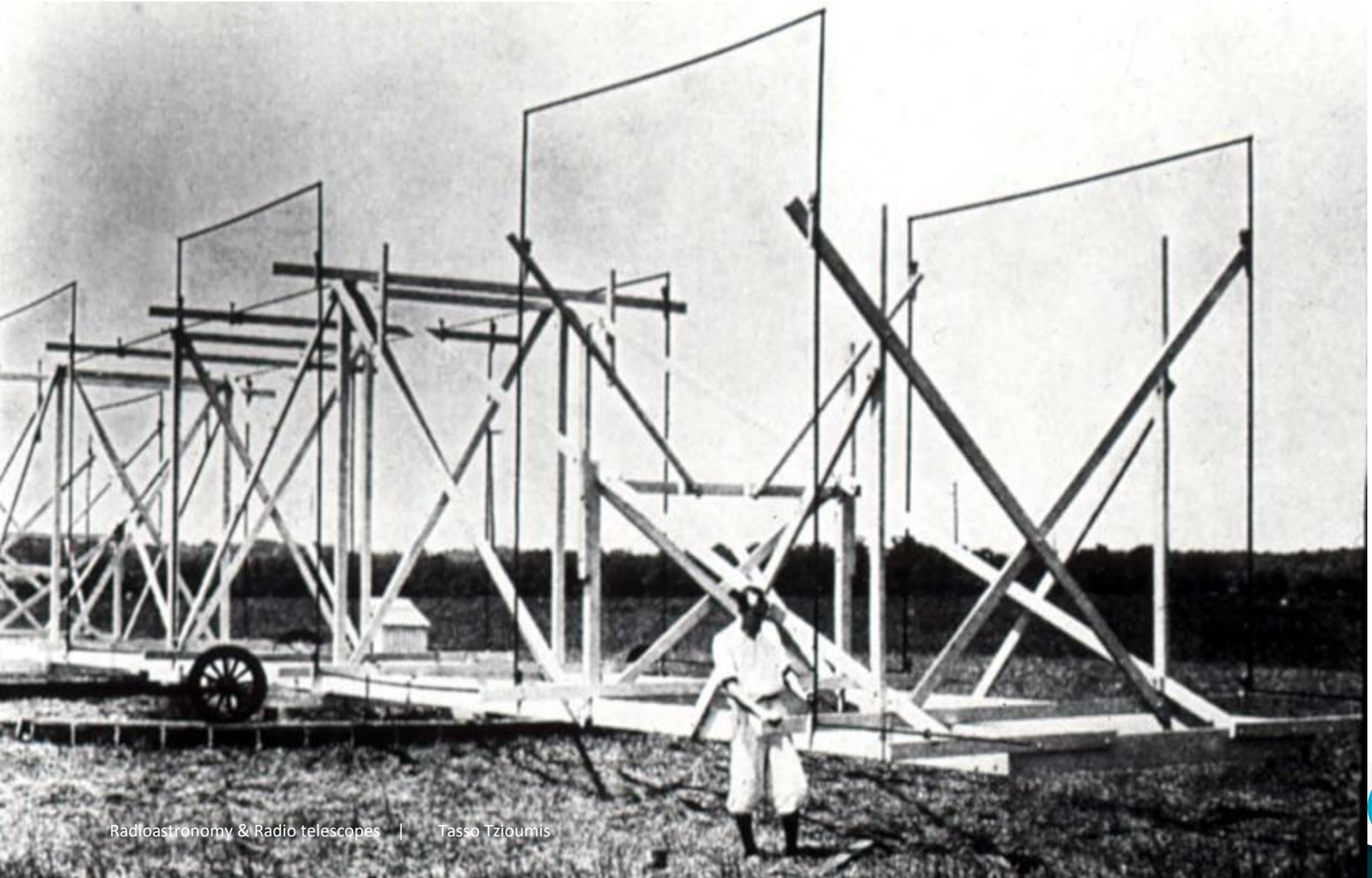
RAS Telescopes

- Brief History
- Telescopes
  - Dishes
  - Arrays
  - Dipole arrays
  - Aperture arrays
  - The (near) Future

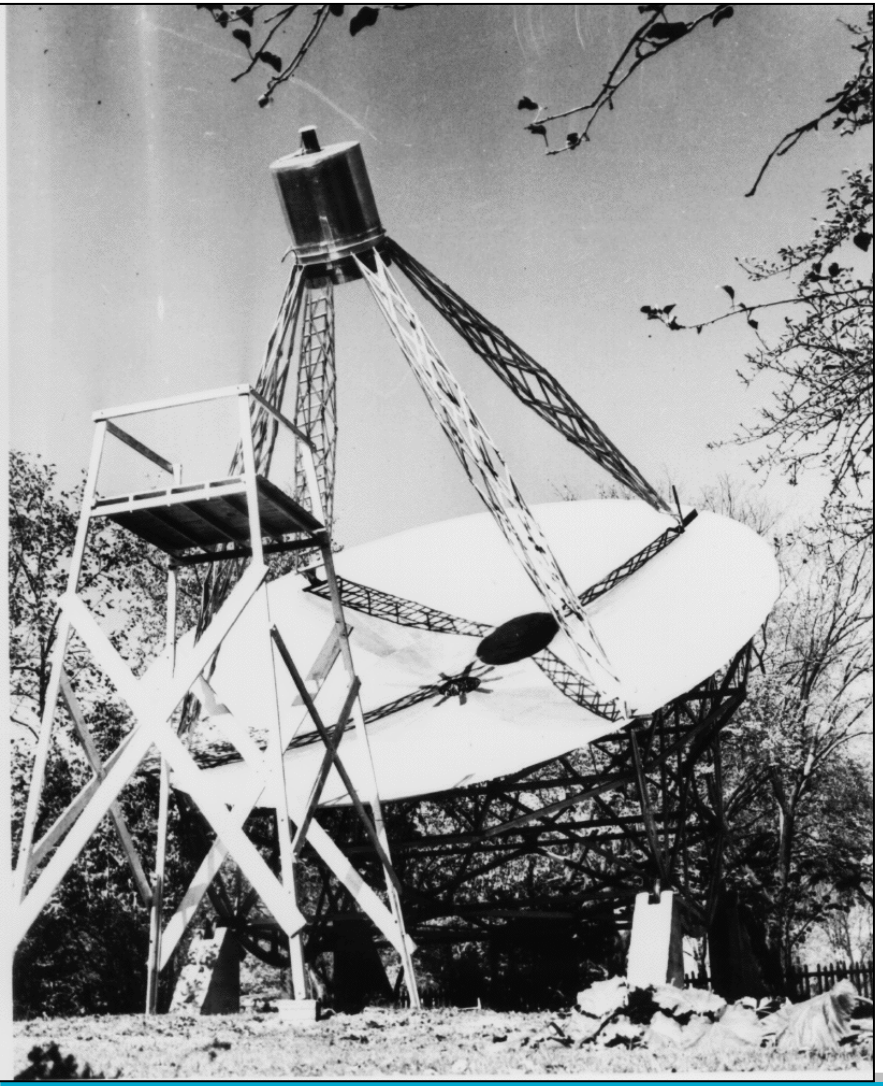
- NOT a comprehensive list
- Just a pictorial guide – no detailed descriptions

Karl Jansky - Bell Telephone Laboratory 1932

Discovery as “cosmic hiss” – interference to communications!!

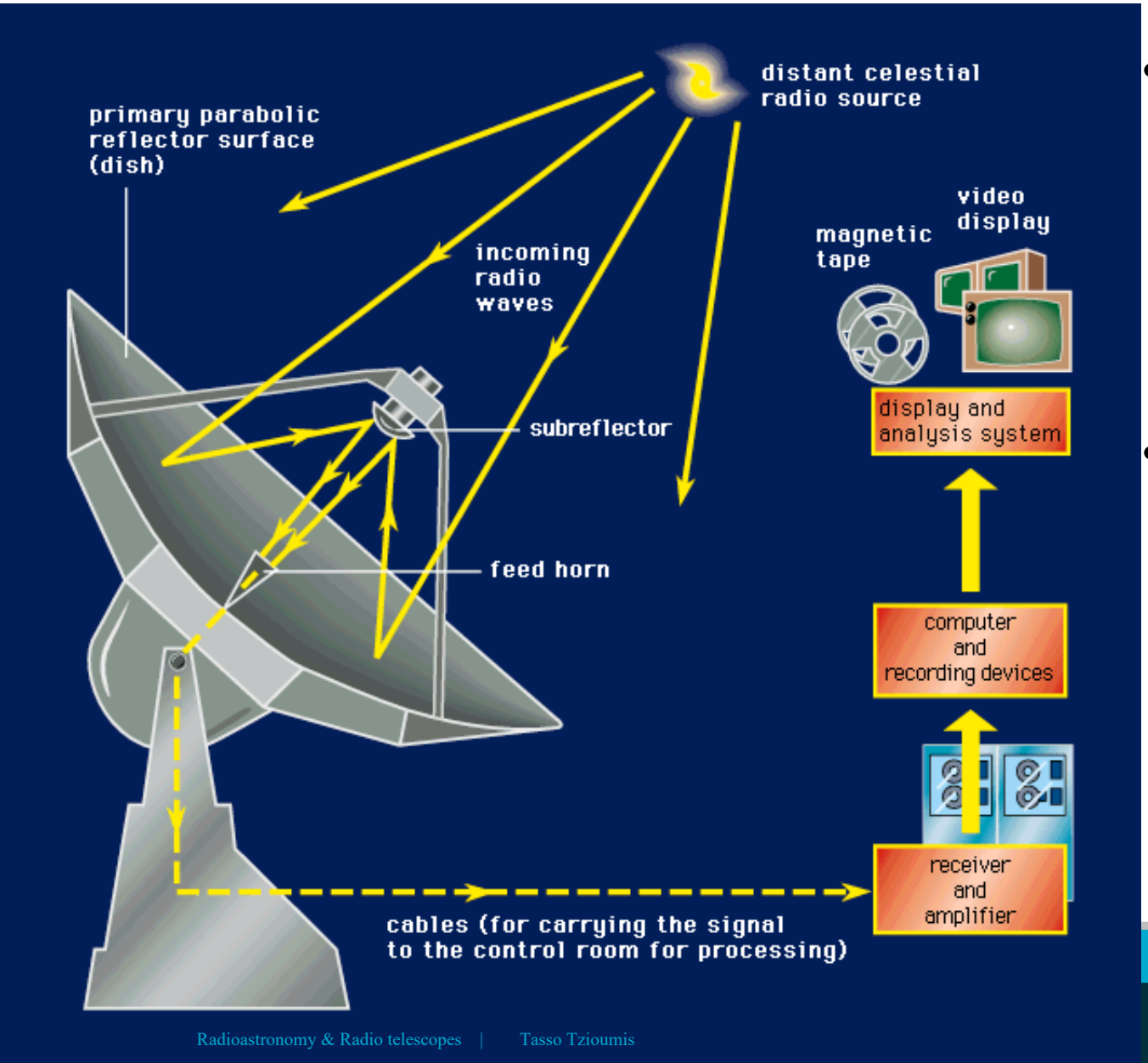


First Dish – Grote Reber 1937
32’ parabola at Home!



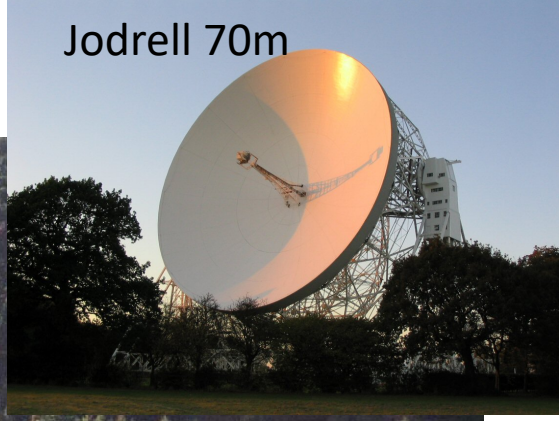
Parkes 64m, Australia 1960

Radio telescope

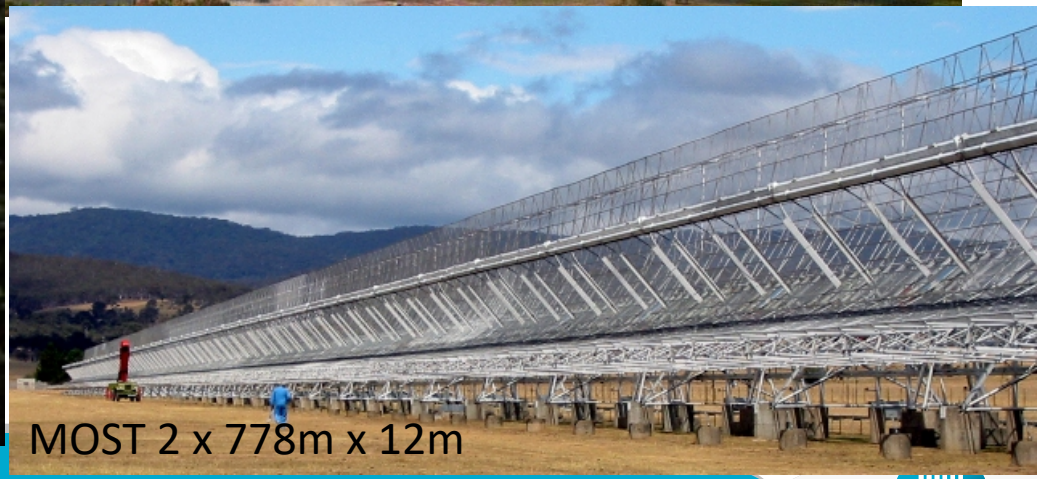


- Mount types:
  - Alt-Az
  - HADEC or Equatorial
  - X-Y
- Feed Geometry:
  - Prime-focus
  - Cassegrain (sub-reflector)
  - Gregorian
  - Beam wave-guide
  - Offset feed

Feeds – Single; Multiple Beams; PAFs

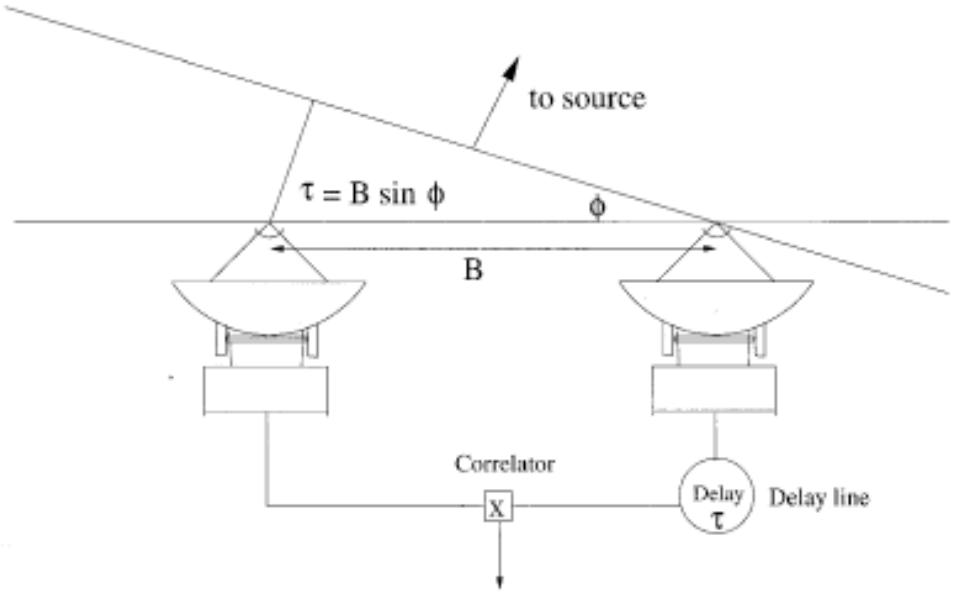


Arecibo 300m (+ Planetary Radar)



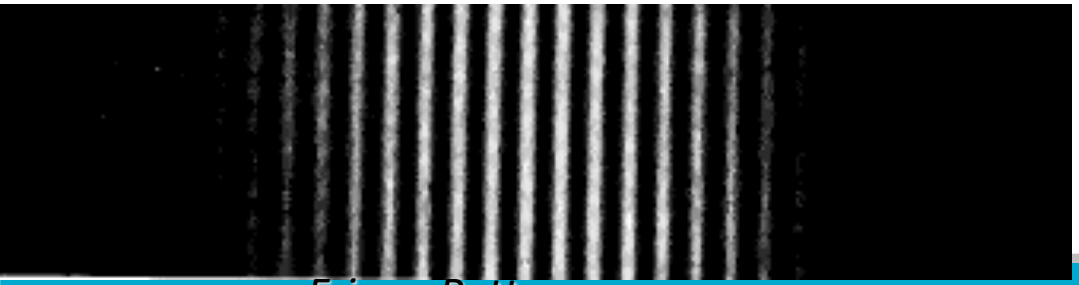
Radio Interferometry

Simple Interferometer



- **Baseline B**: Distance between antennas

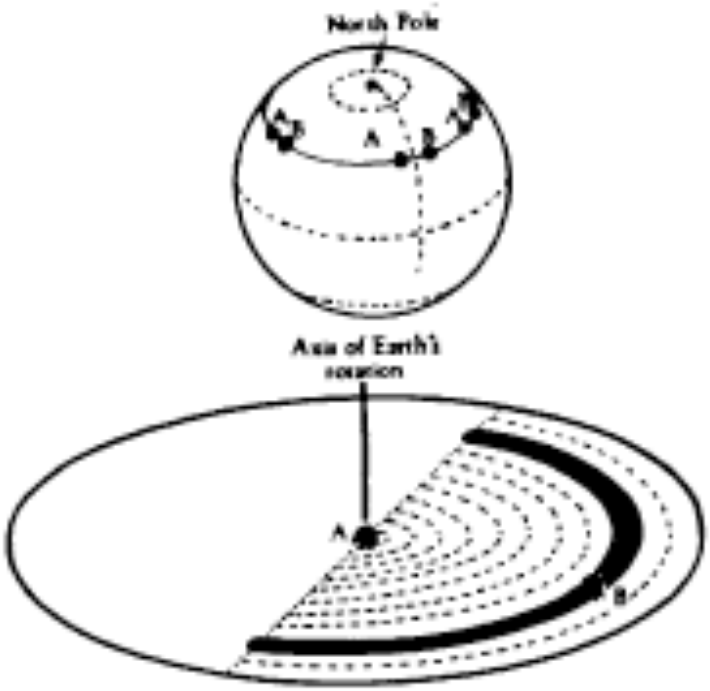
- "Virtual" telescope of diameter **B.cos ϕ** *(projected baseline)*

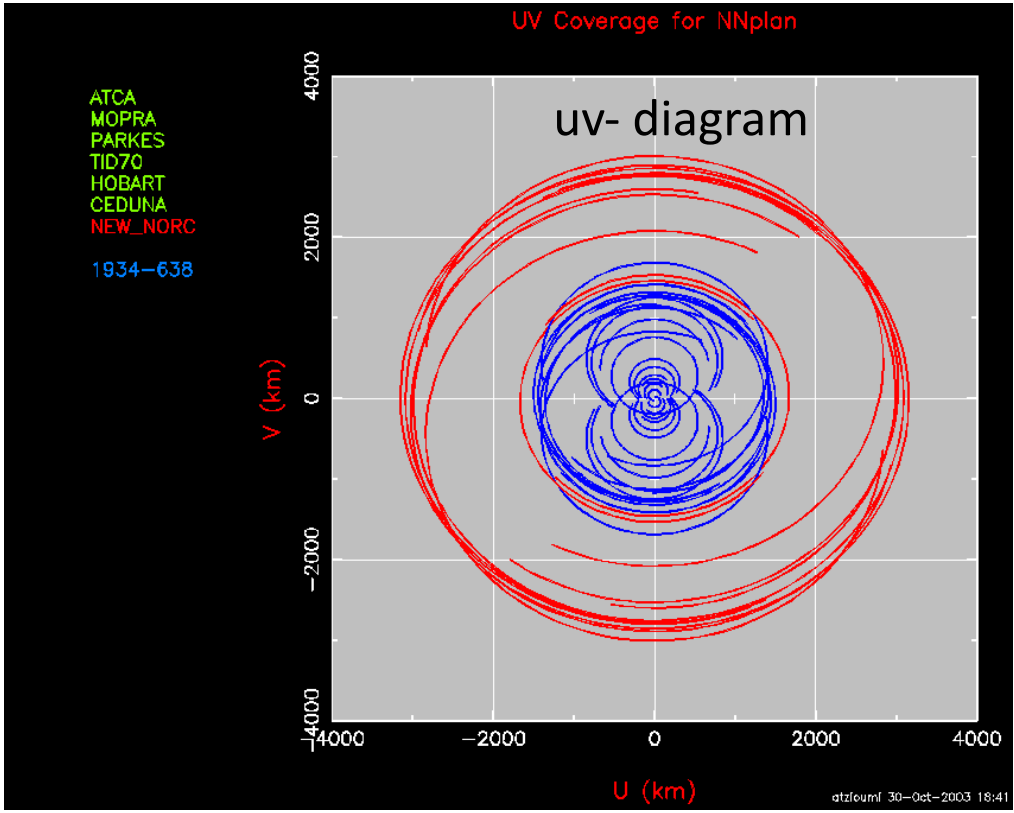


Fringe Pattern

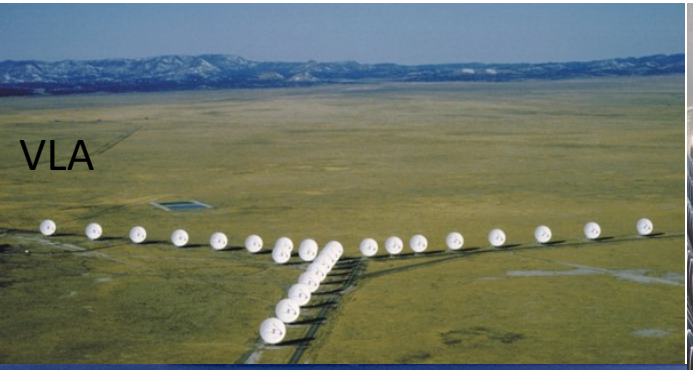
- Fringe pattern provides information on structure and position of the radio source

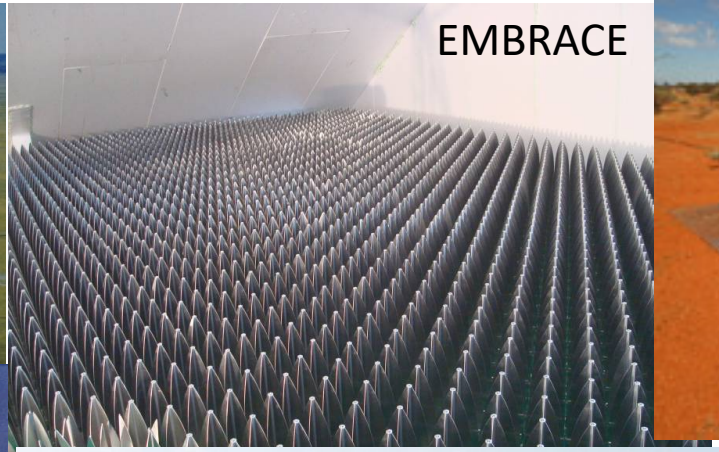
Earth Rotation Aperture Synthesis





- Baseline length and orientation (as viewed from the source) changes as the Earth rotates ⇒ new information on source structure.
- **uv-diagram** - an indicator of imaging "quality" of an array of antennas
  - more antennas ⇒ filled uv ⇒ better image fidelity


VLA


EMBRACE


MWA


ATCA


LOFAR

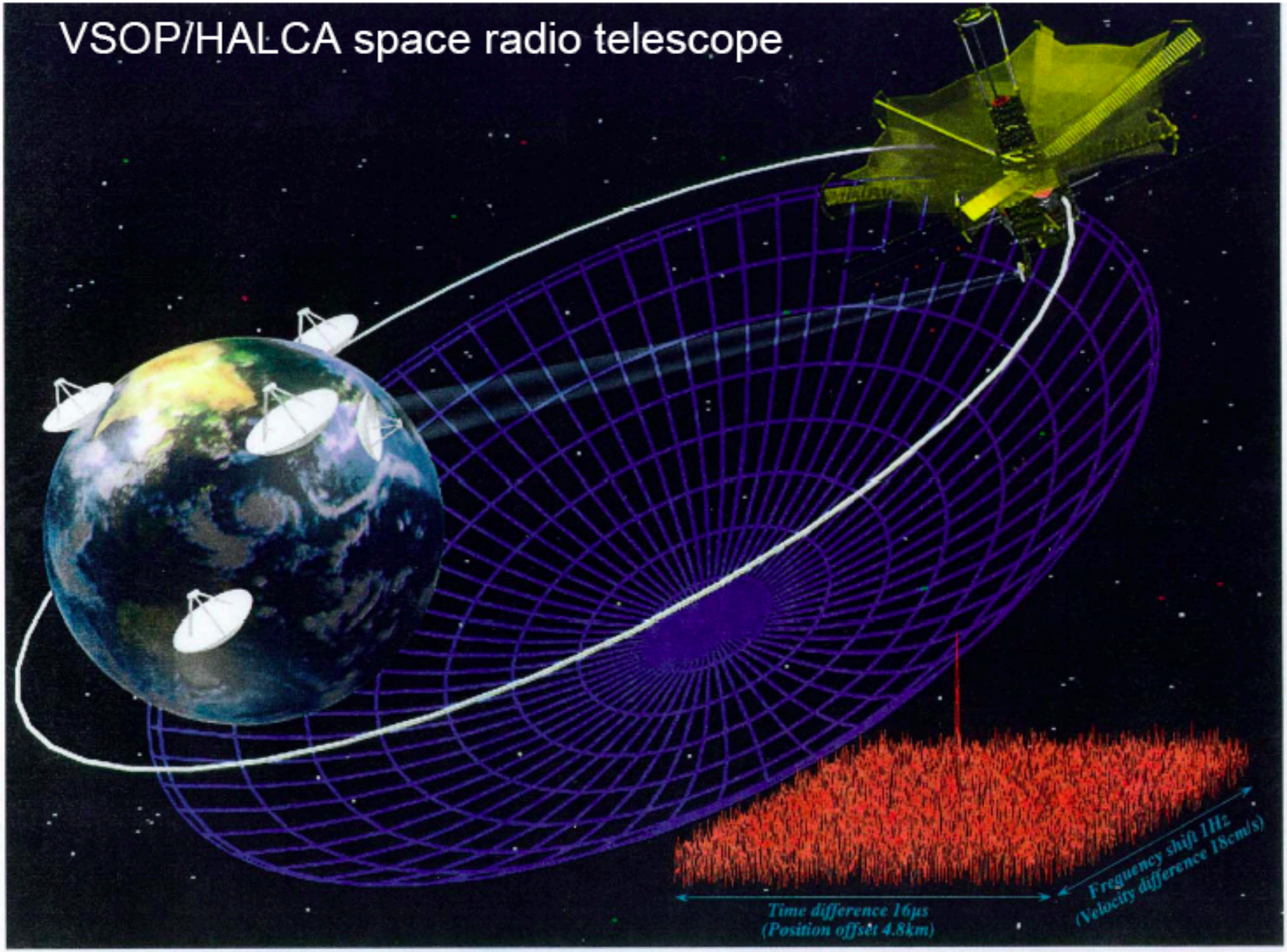

ASKAP


ALMA


MeerKAT

VLBA – only dedicated VLBI array

EVN - European VLBI Network



The ISAS satellite HALCA and the Usuda 64m antenna conducted their first successful interferometric test on 7th May 1997 during observations

Why?

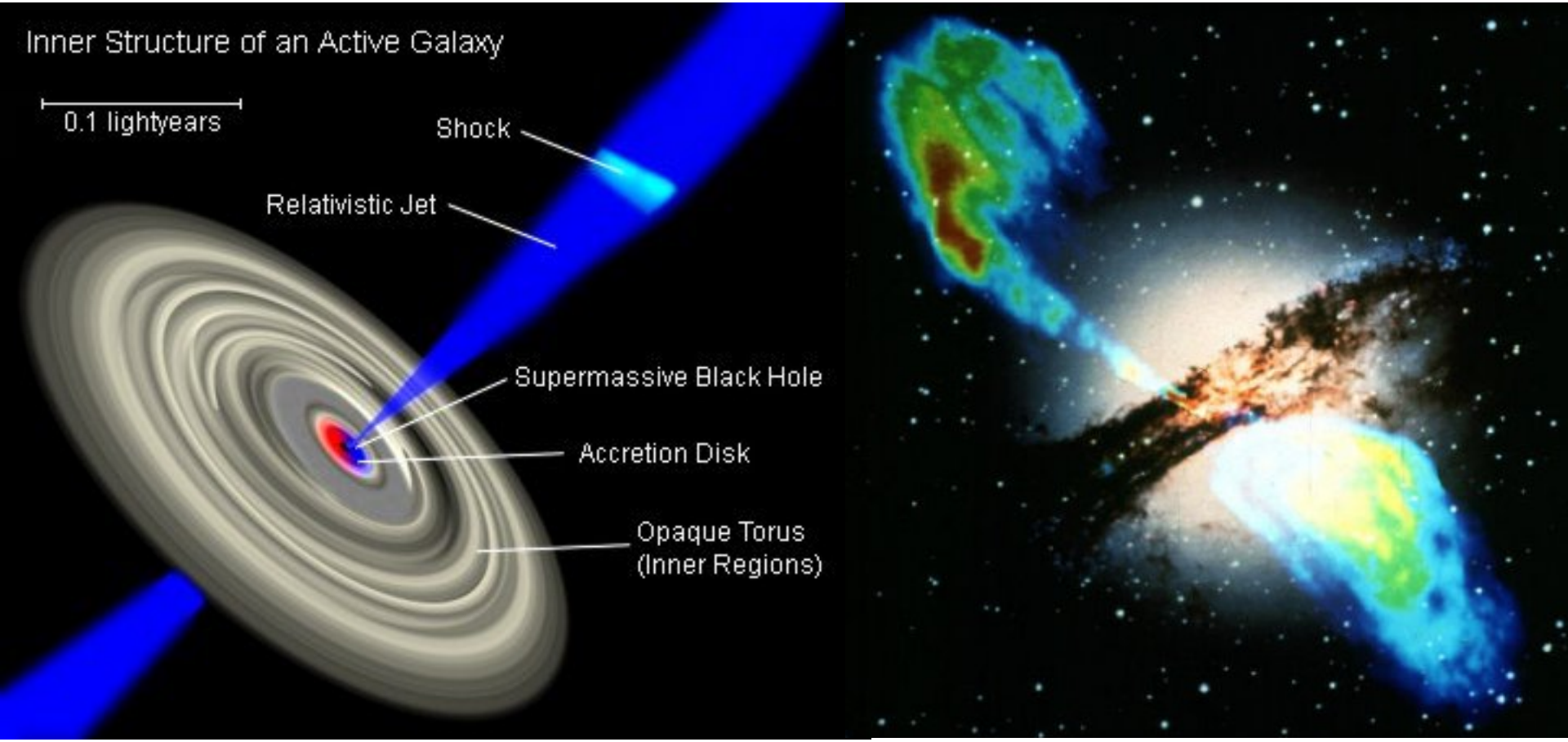
The wonders of the Universe

A very eclectic selection:
mainly work that I have been involved with
(every astronomer would have a different list)

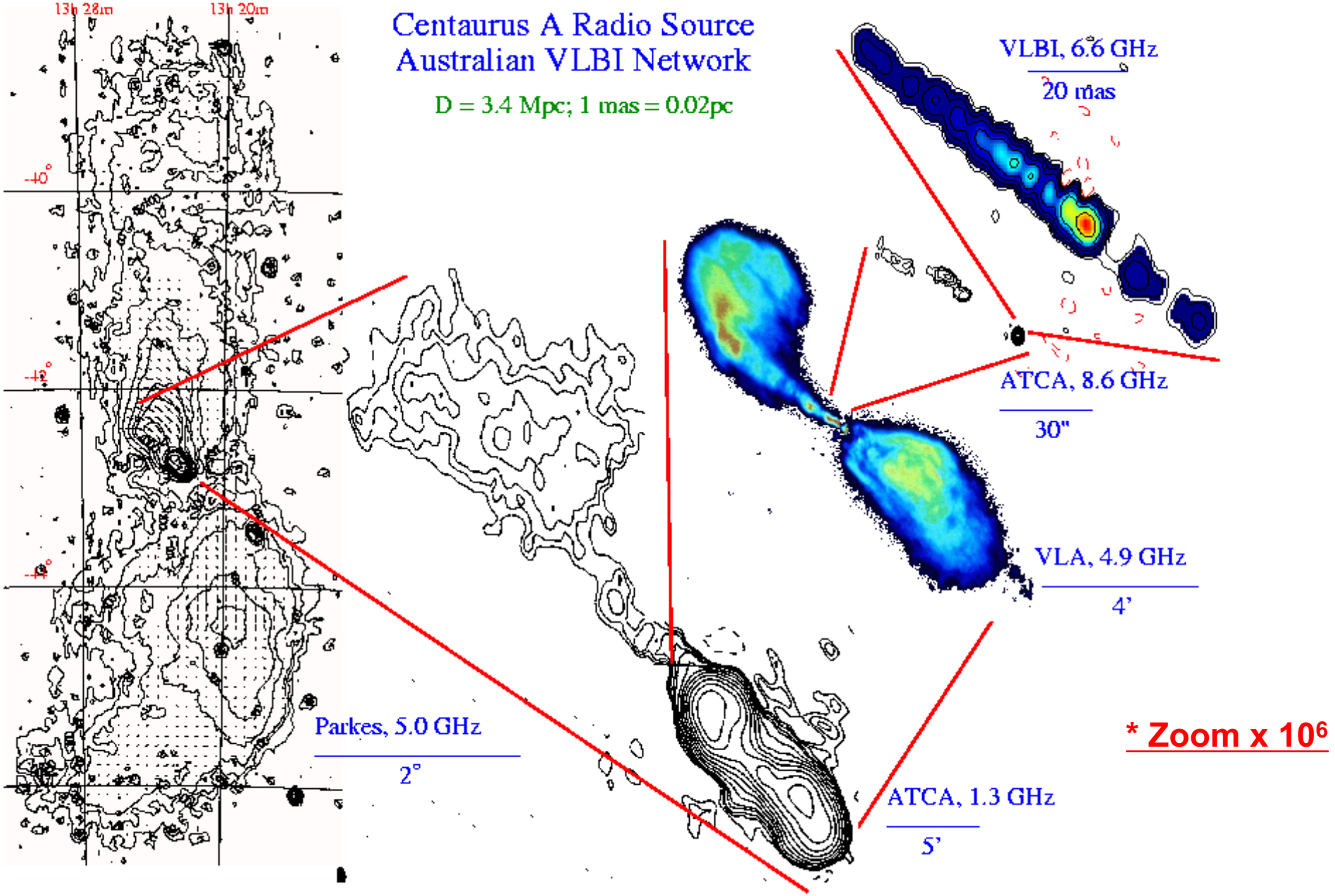
Black Holes and Jets in Galaxies

Model

Centaurus-A Galaxy
Optical + Radio



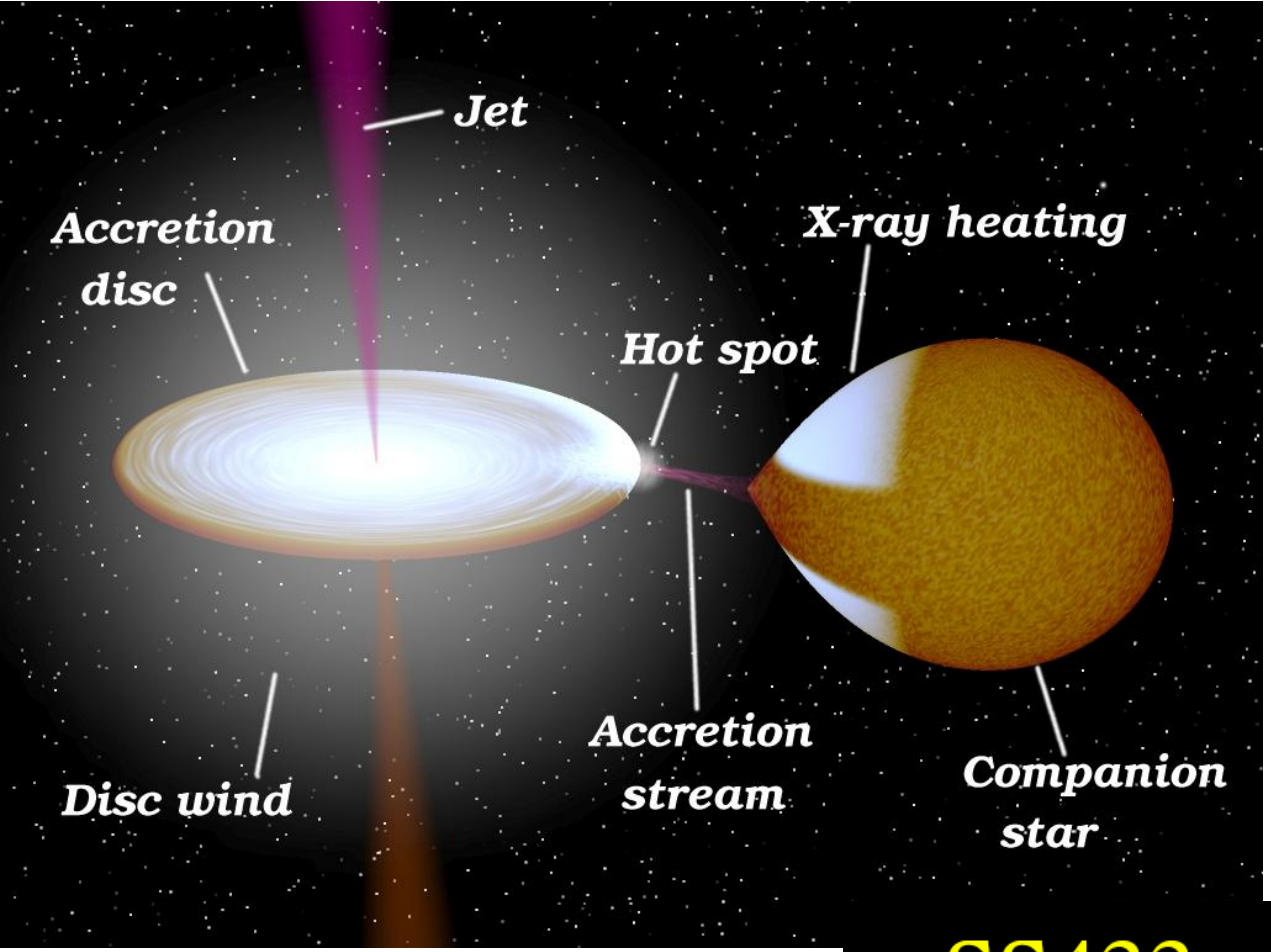
Nearest Active Galaxy – Central Black Hole + Jets



*** Zoom x 10^6**

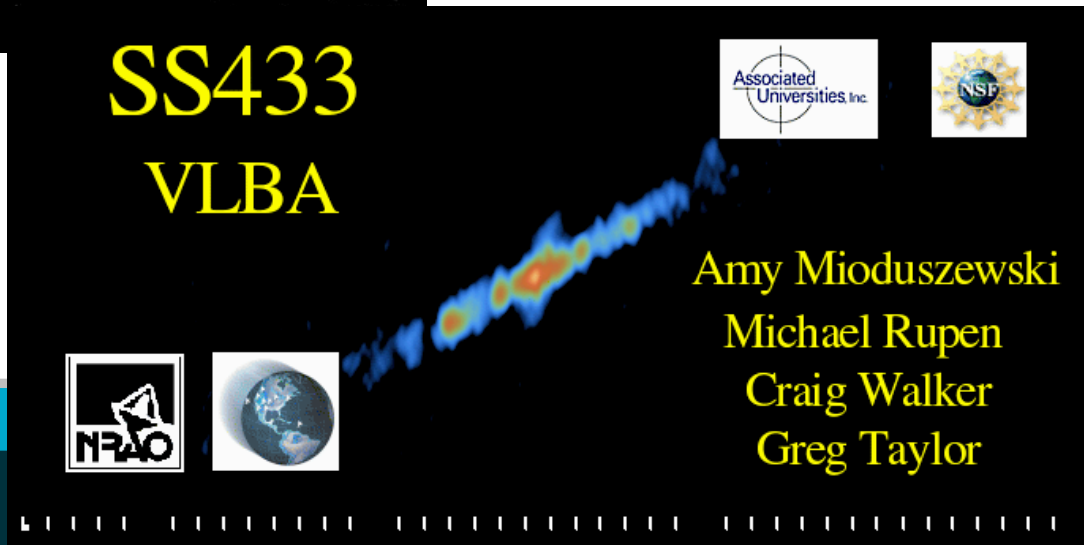
SS433

- **X-ray binary**
- Precessing jets
- 0.26c jet speed
- Baryonic jets



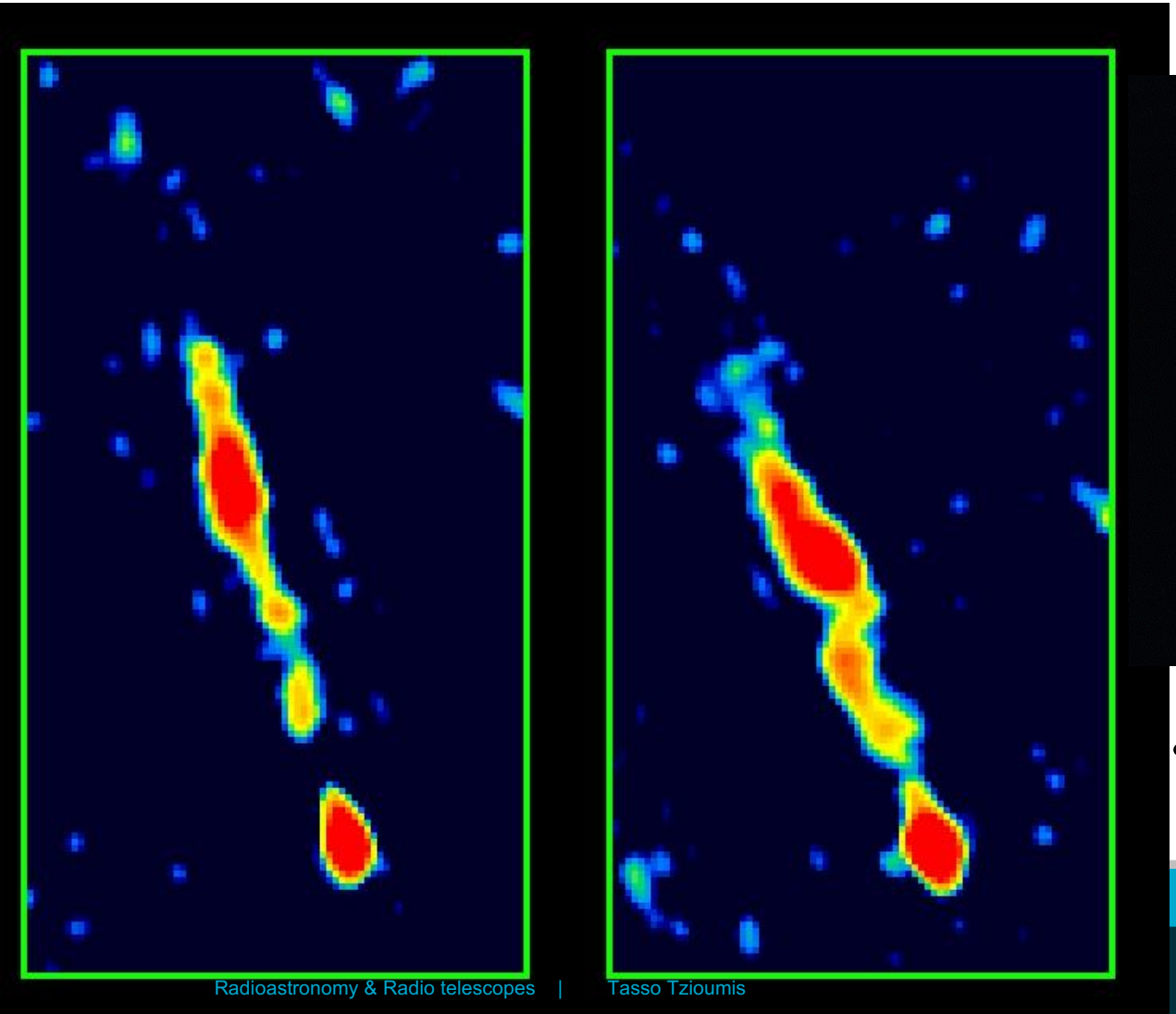
Model

Movie of VLBI Observations

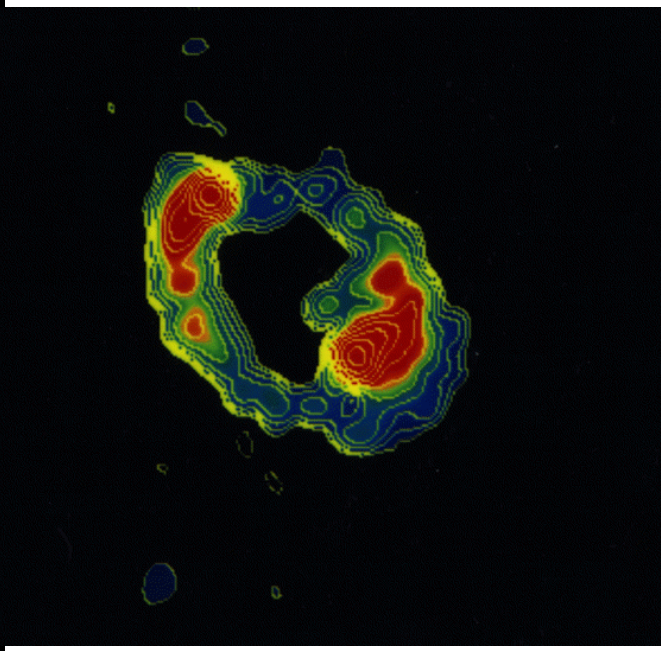


Gravitational lensing

Double-quasar 0957+561 - VLBA+EVN, 18cm

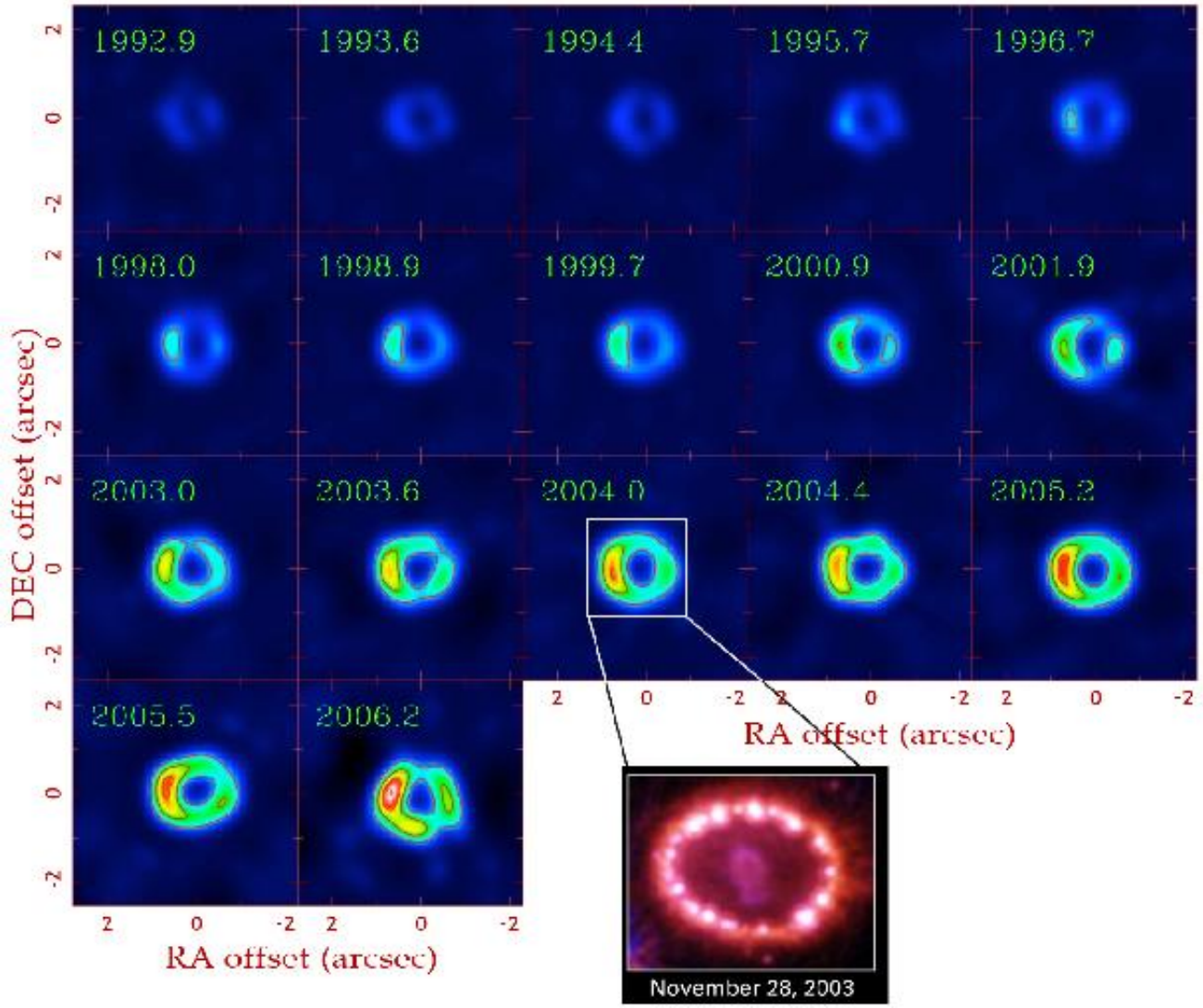


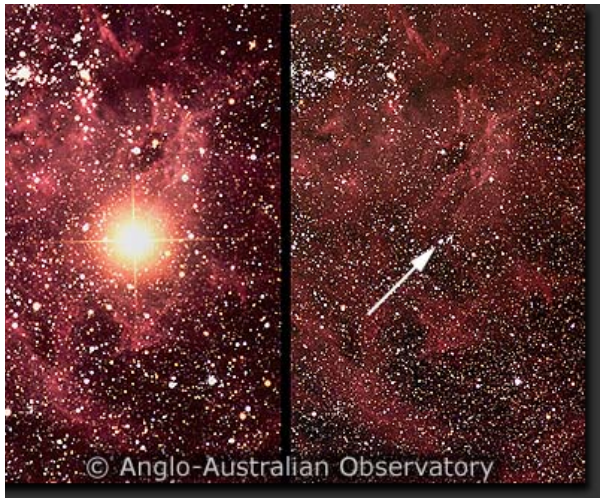
PKS1830-211
Einstein Ring
MERLIN, 5cm



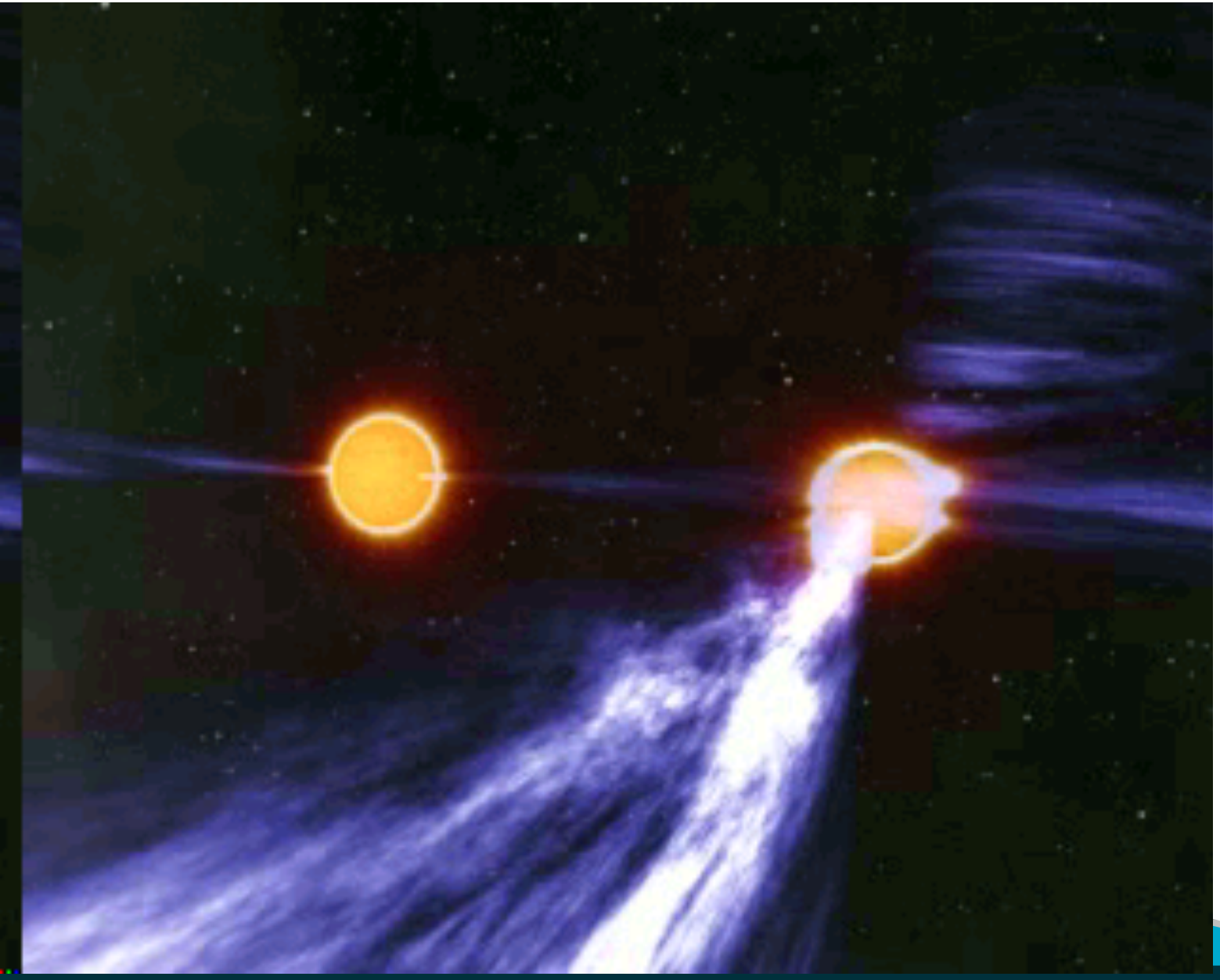
- Lensing of background quasar by intervening massive galaxy cluster

The evolving supernova remnant 1987A

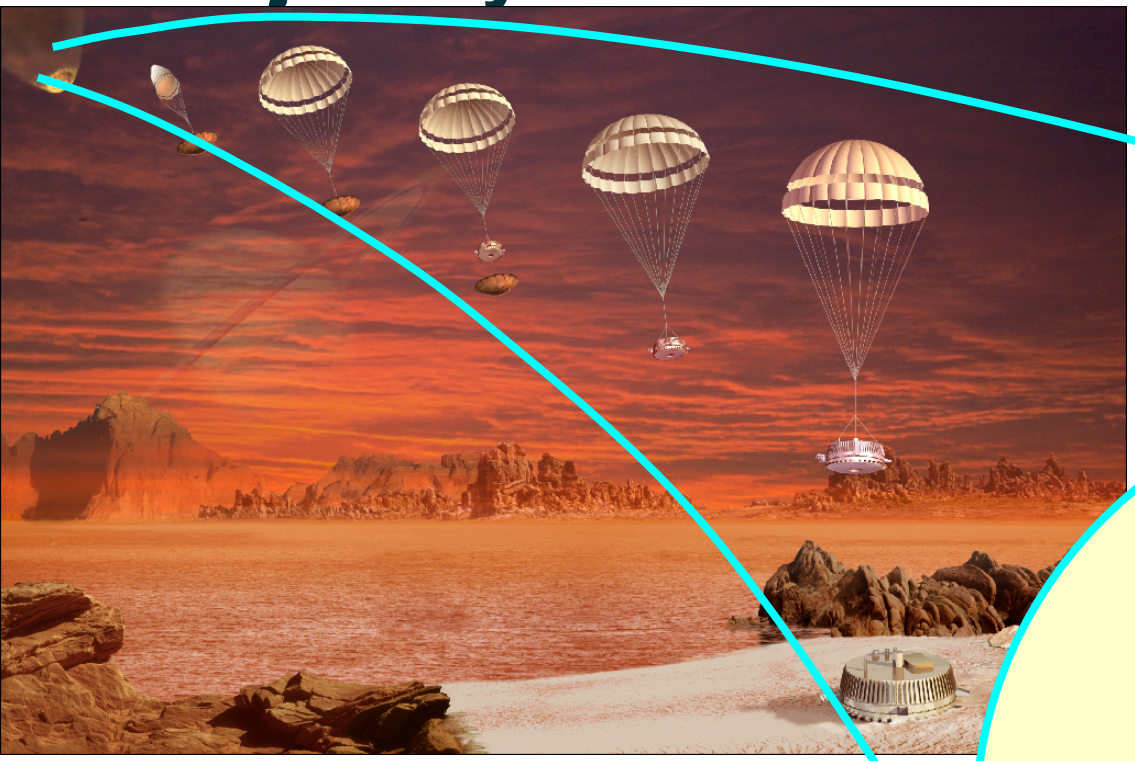




Pulsars - Cosmic lighthouses



VLBI determination of the Huygens descent trajectory



A priori accuracy: ~100 km

“Doppler interferometry”:

Full VLBI accuracy: ~ 1 km

The Future

Square Kilometre Array

SKA

Square Kilometre Array

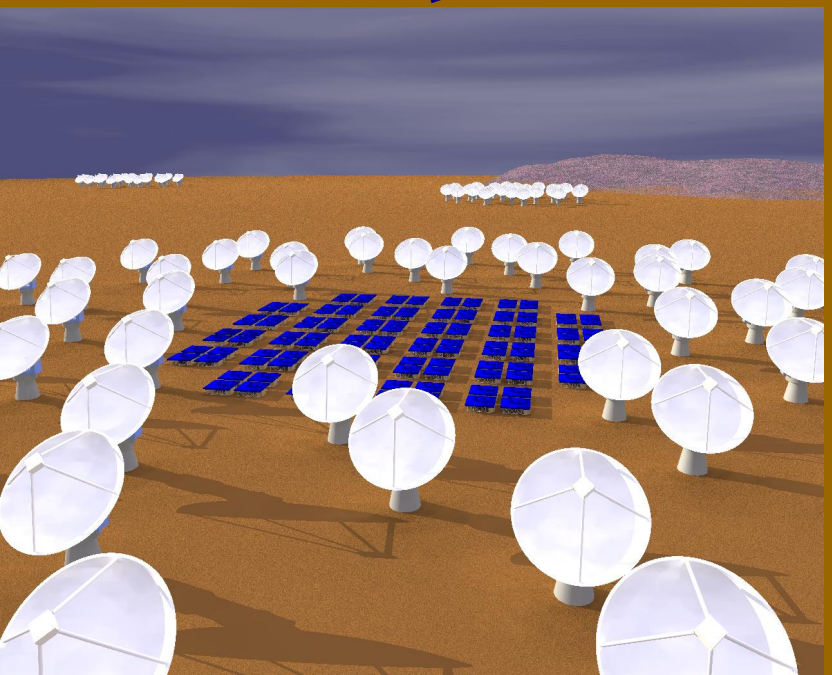
Current radio telescopes based on pre-1980s technology

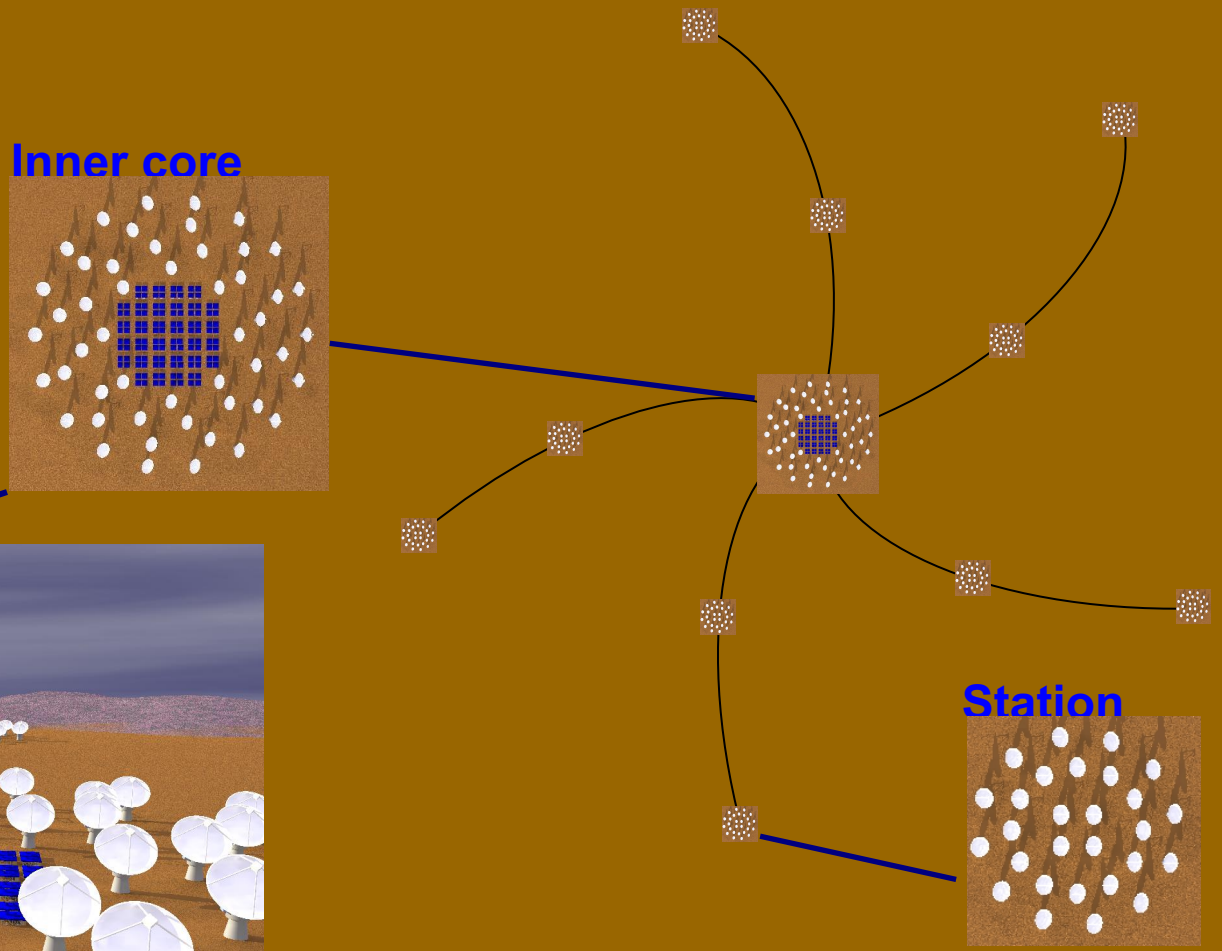
Science now demands:

1. Large increase in sensitivity $\rightarrow$ 1km^2 (~50 x)
   - Observe neutral hydrogen throughout the universe
2. Large increase in field-of-view $\rightarrow$ 50deg^2 (~200x)
   - Survey entire sky
3. High spatial resolution $\rightarrow$ 1mas (Already achieved)
   - Resolve protoplanetary disks

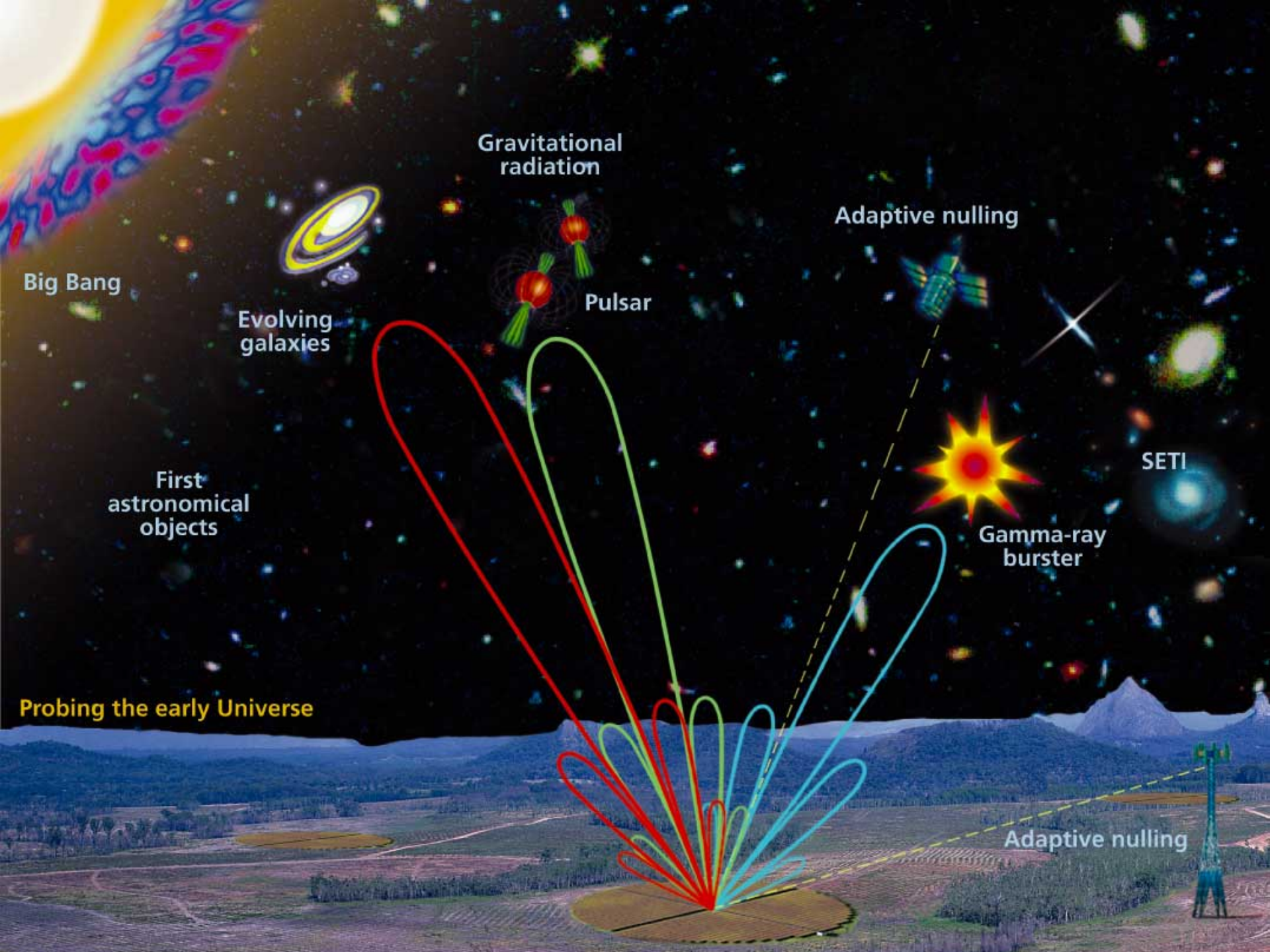
Discovery Potential = Area X f.o.v. ~ 10000 x

Reference Design



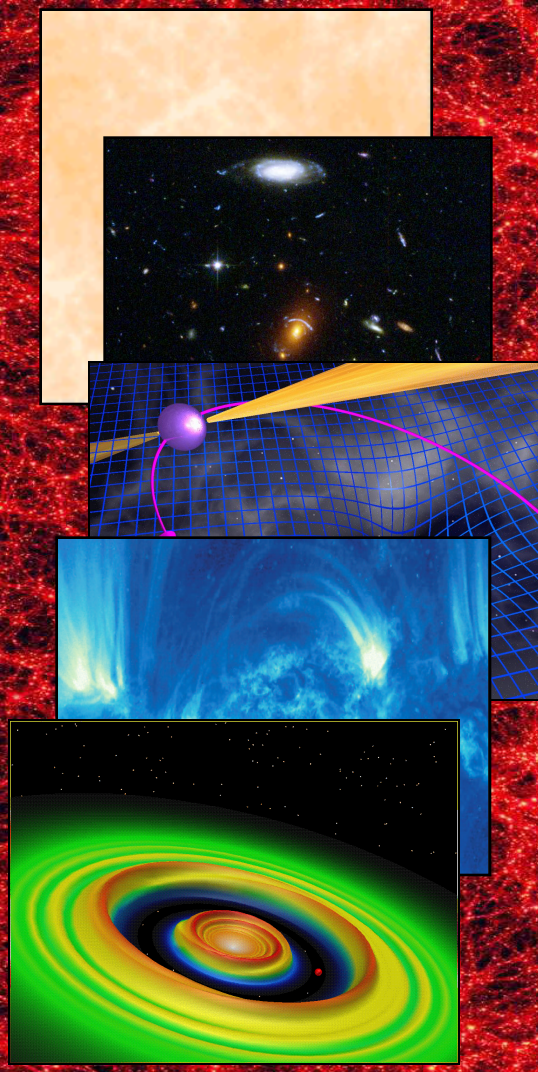


Wide-angle radio camera + radio “fish-eye lens”


Gravitational radiation
Adaptive nulling
Big Bang
Evolving galaxies
Pulsar
First astronomical objects
SETI
Gamma-ray burster
Probing the early Universe
Adaptive nulling

SKA Key Science Drivers

- Probing the Dark Ages
  - When & how were the first stars formed?
- Cosmology and Galaxy Evolution
  - Nature of Dark Energy and Dark Matter
- Strong-field tests of General Relativity
  - Was Einstein correct?
- Origin & Evolution of Cosmic Magnetism
  - Where does magnetism come from?
- Cradle of Life
  - What and where are the conditions for life?



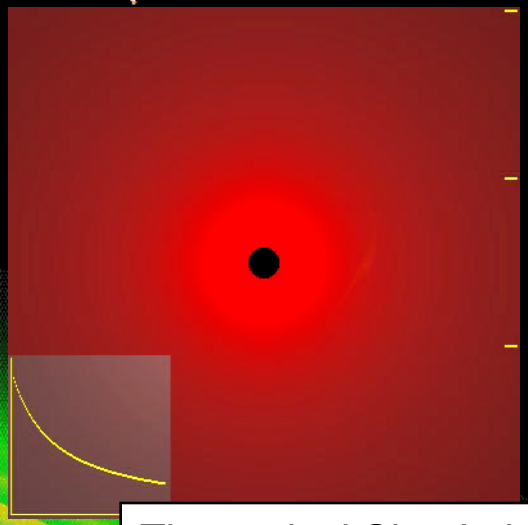
The Cradle of Life

SKA Role

Movies of proto-planetary disks in formation

cm λ

milliarcsec resolution



Theoretical Simulation

Composition of 'building blocks' of disks

Probe the 'Habitable zone' in disks

Complements ALMA

Complementary to (and surpasses) ALMA/ELT

Thank you

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